Non-opaque and Opaque Ice Cloud Properties from Infrared Radiances at 3.7, 6.7, 11.0, and 12.0 μm

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IR Retrieval?

- weather and climate modeling
  - cloud diurnal cycle
  - cloud climatology, long term variation

- is still remained the challenge
  - Not like VIS, IR radiances of clouds are more sensitive to cloud and atmospheric profiles
  - IR blackbody limitation, effective emissivity close to 1, reliable Tau < 6-8

Only 3.7, 6.7, 11.0, and 12.0-µm bands?

- focus on retrieval algorithms using fewer IR bands, mostly common.

- cloud retrieval algorithms utilized as few channels that are common to most meteorological satellite imagers as possible have the advantage of producing consistent cloud properties (Minnis et al., 2011)

Objectives

- physical retrievals of cloud-top temperature/height, effective emissivity, Tau for non-opaque ice clouds
- neural network training for opaque ice cloud Tau

Estimating Non-opaque Ice Cloud Tc from 6.7 and 11.0-µm Radiances

Current CERES nighttime cloud retrieval algorithm:
The Shortwave-infrared Infrared Split-window Technique (SIST) for all surfaces at night (CERES, Minnis et al.,1998; 2011) using 3.7, 11.0, and 12.0 µm.

When there is no 3.7 or 12 µm available (e.g., some GEOs)

Szejwach (1982)

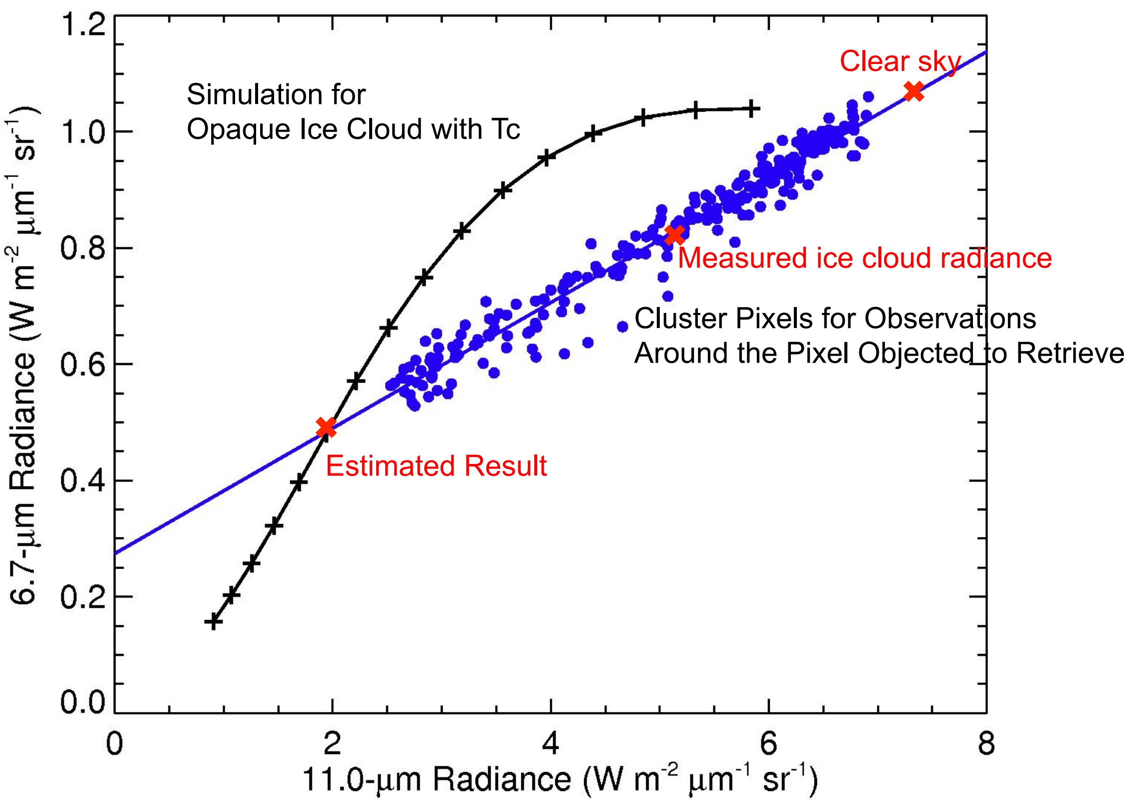
$$I_{WV} = (1 - N\varepsilon_{WV}) \cdot I_{WV}^{clear} + N\varepsilon_{WV} \cdot I_{WV}^{cloud}$$

$$I_{11} = (1 - N\varepsilon_{11}) \cdot I_{11}^{clear} + N\varepsilon_{11} \cdot I_{11}^{cloud}$$

Clear Sky Radiance

$$\frac{I_{WV} - I_{WV}^{clear}}{I_{11} - I_{11}^{clear}} = \frac{\cancel{N\varepsilon_{WV}}(I_{WV}^{cloud} - I_{WV}^{clear})}{\cancel{N\varepsilon_{11}}(I_{11}^{cloud} - I_{11}^{clear})}$$

Satellite Measured Radiance Effective Emissivity Cloud Radiance at Tc Blackbody



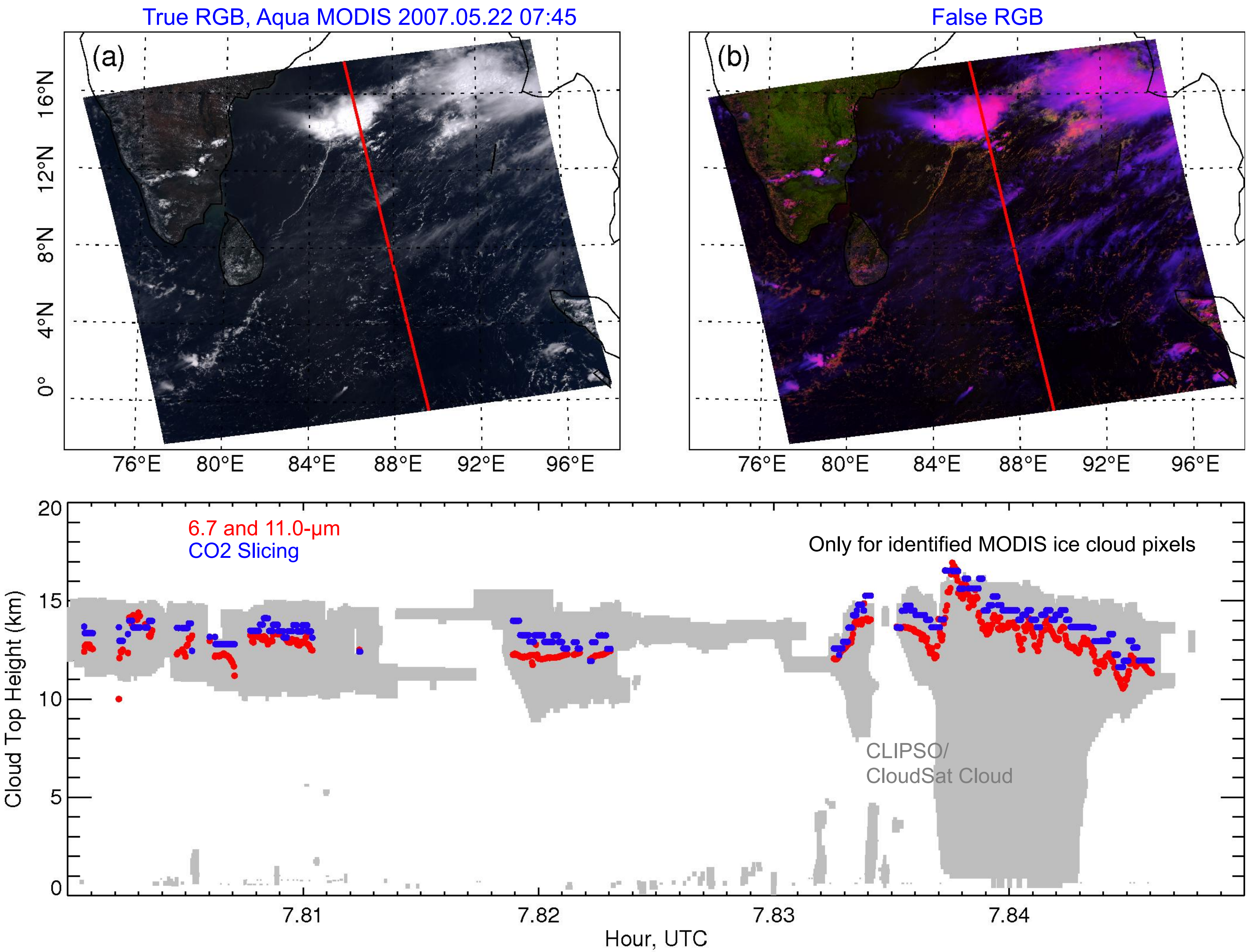
Pixel-based:
Tc is derived by matching the ratio along black line

Could be strongly affected by variation of clear sky radiance

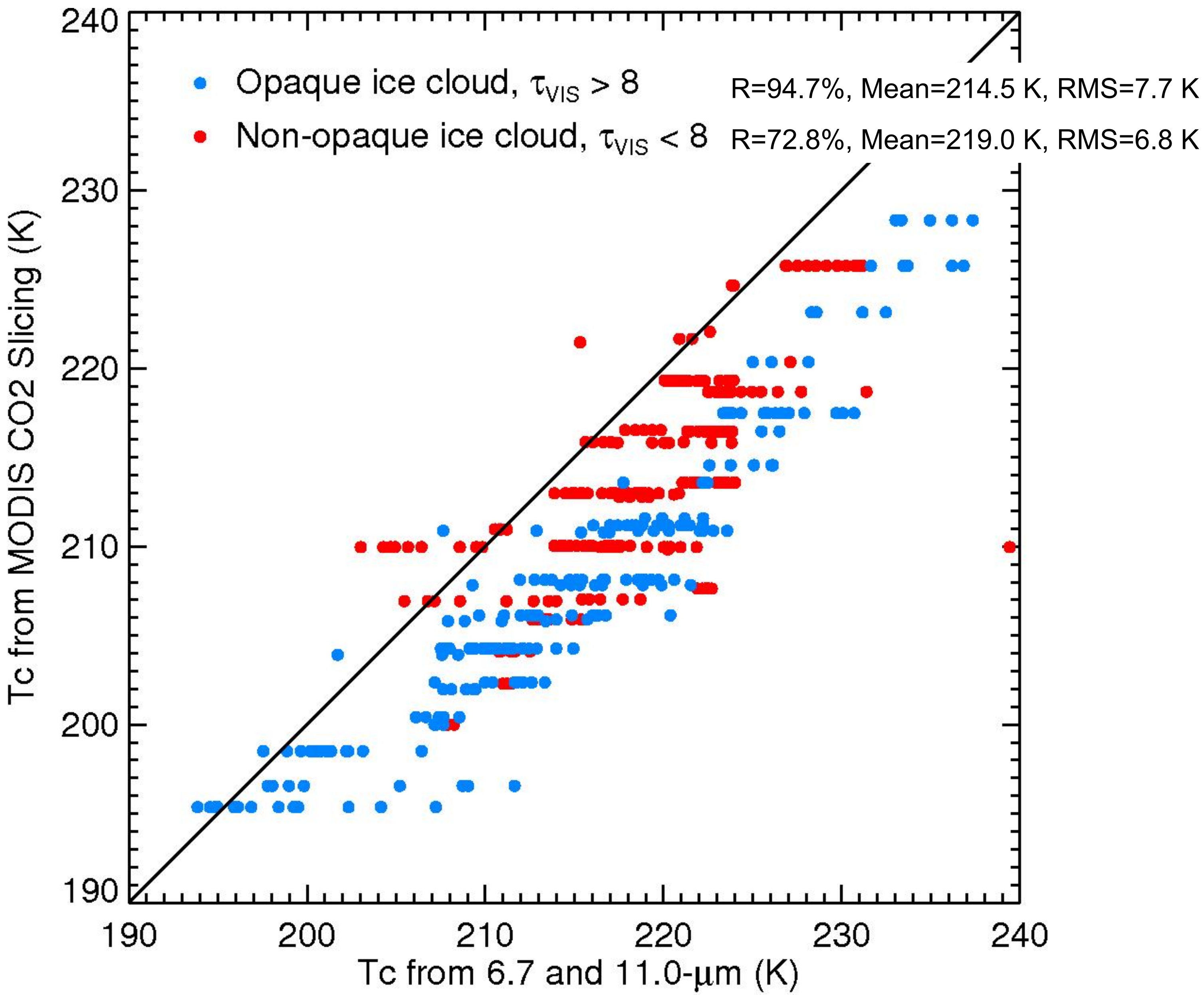
Cluster-based:
Linear fitting cluster pixels, crossing with simulated opaque ice cloud ratio (black line)

Could be less affected by variation of clear sky radiance with respect to pixel-based method.

Ice Cloud Top Temperatures/Heights



Ice Cloud Top Temperatures/Heights



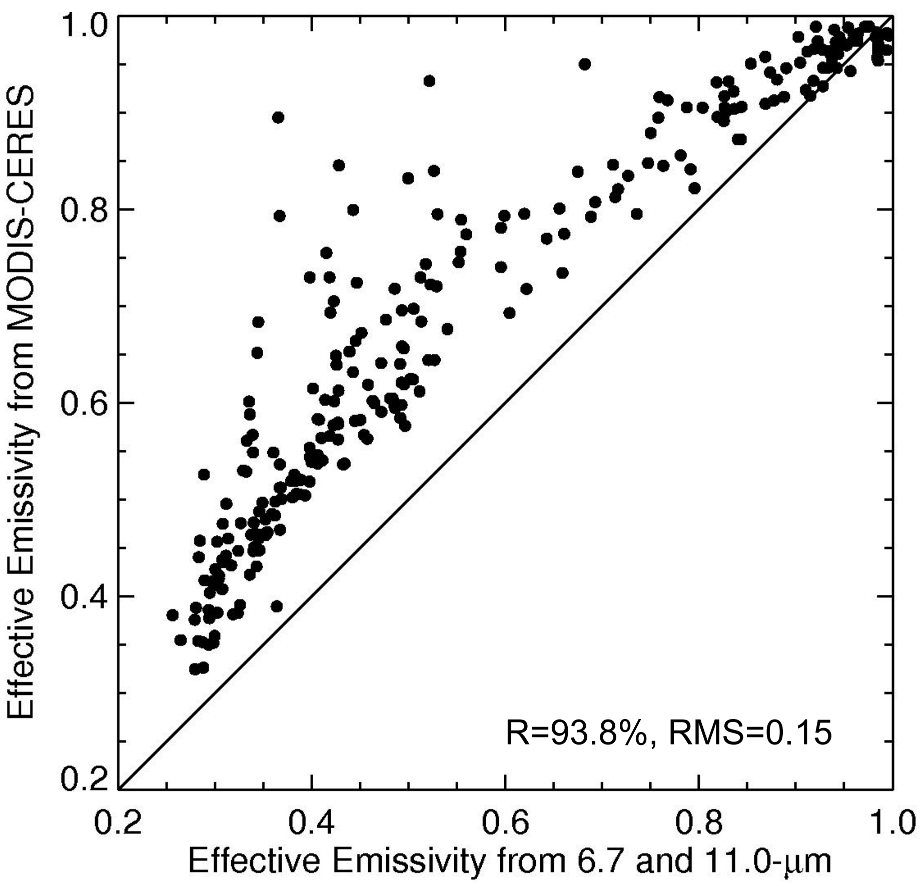
Non-opaque Ice Cloud Effective Emissivity and Optical Thickness (1)

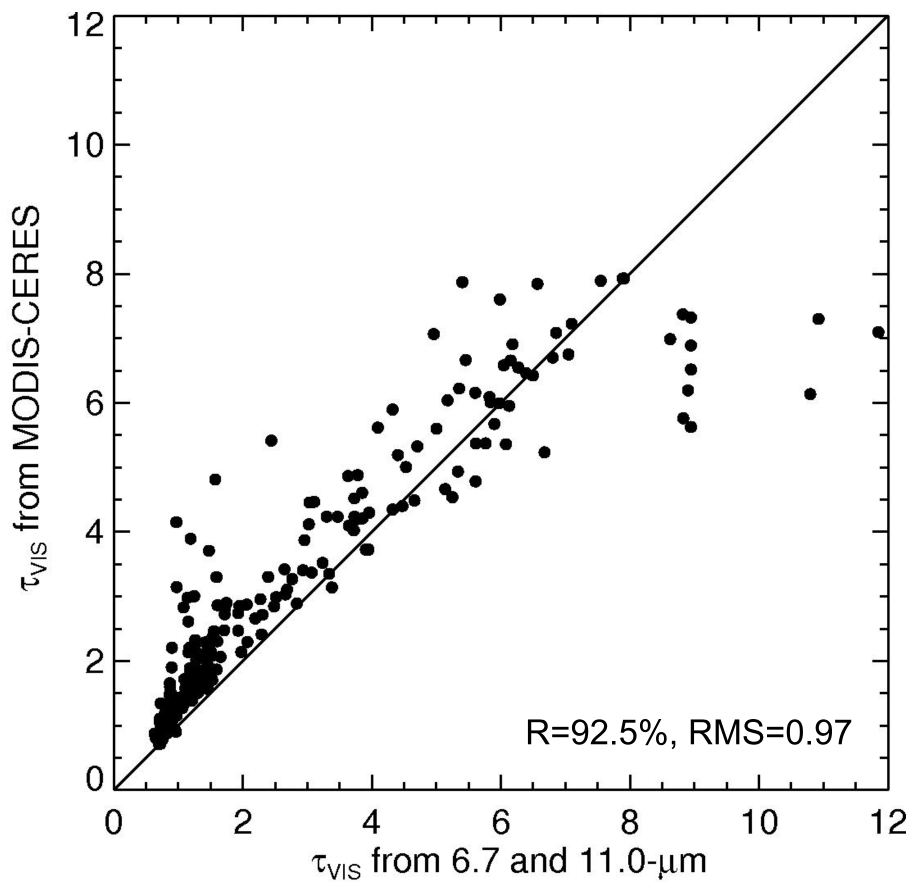
Once obtaining Tc for non-opaque ice clouds, *Nε* is derived from

$$I_{11} = (1 - N\varepsilon_{11}) \cdot I_{11}^{clear} + N\varepsilon_{11} \cdot I_{11}^{cloud}$$

Nε is then converted to visible optical thickness using parameterizations from Minnis et al. (1993, 1998),

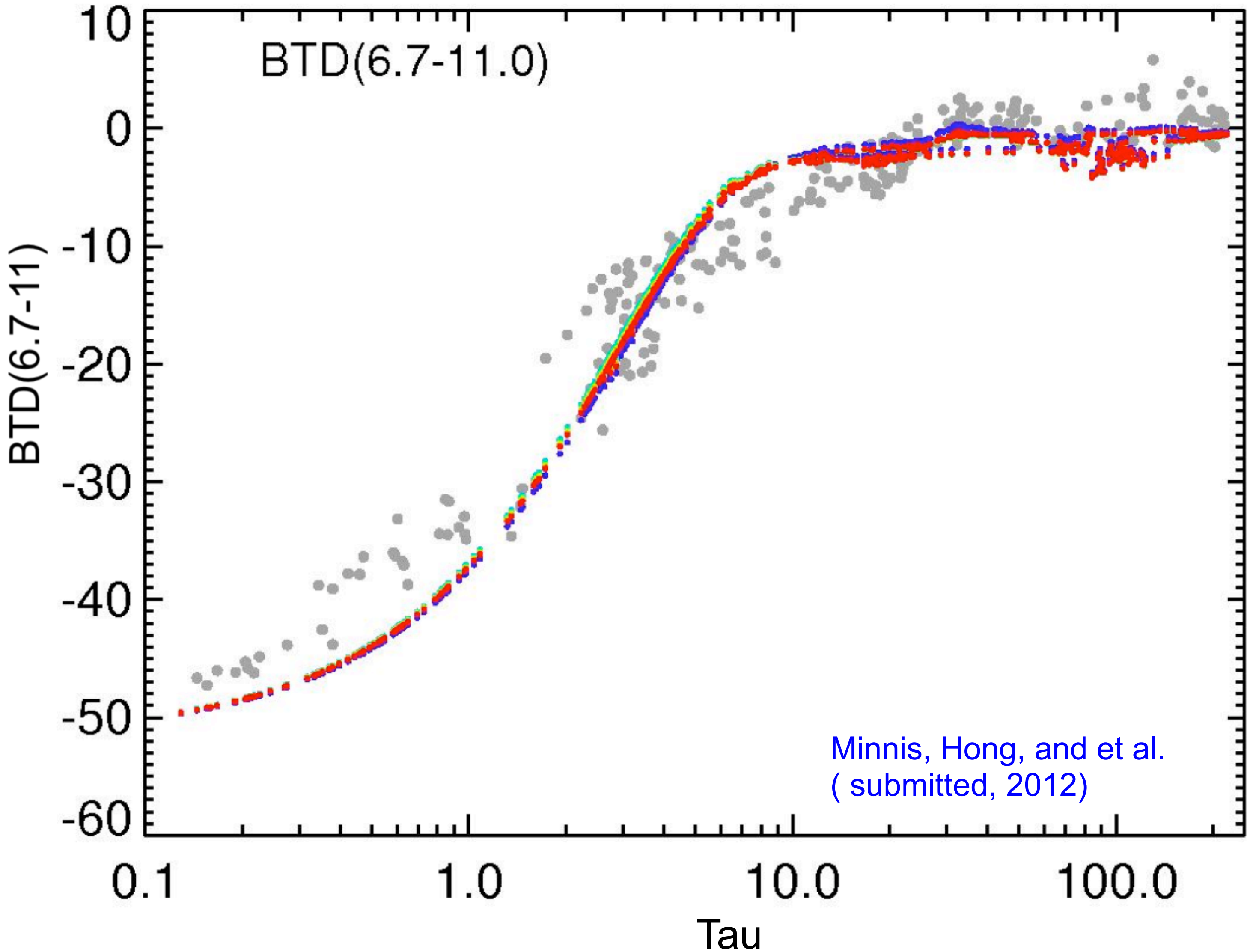
$$\tau_{VIS} = -2.13 \cdot \ln(1 - N\varepsilon)$$





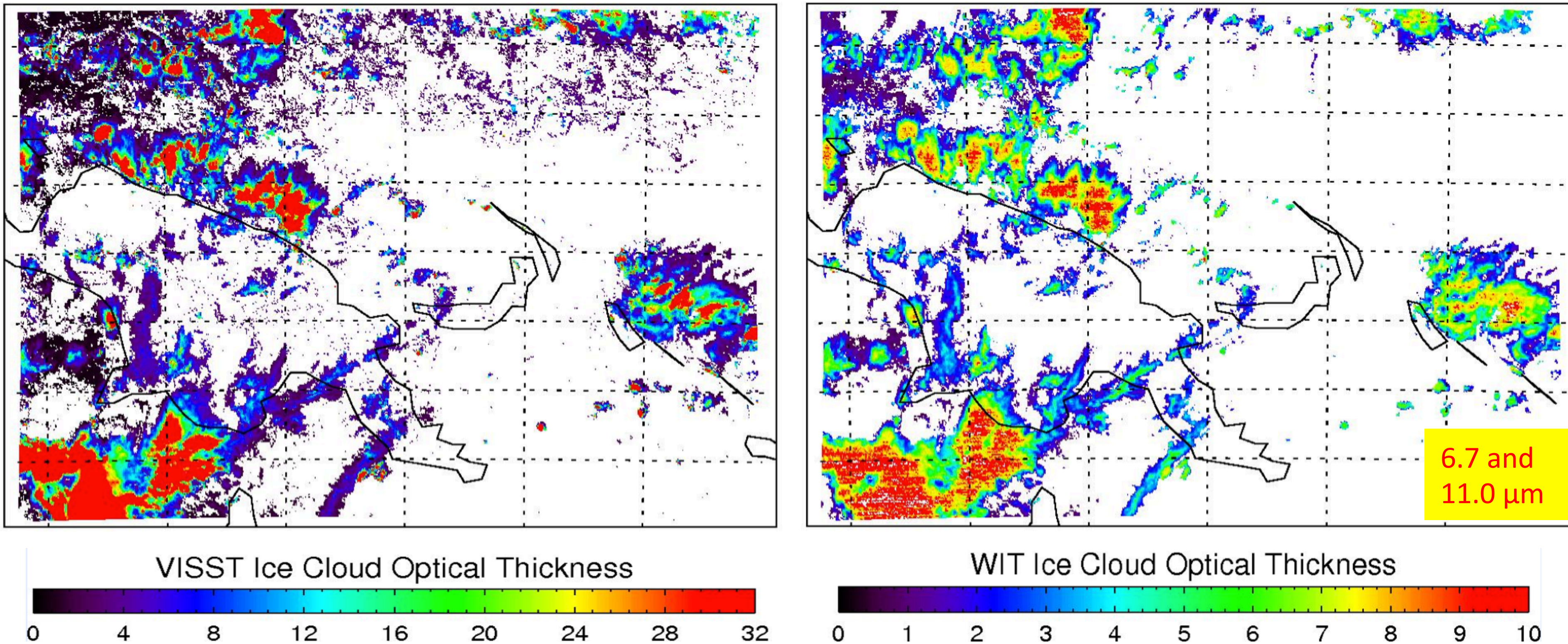
Non-opaque Ice Cloud Optical Thickness from 6.7 and 11.0 µm (2)

Using BTD(6.7-11.0) for Tau,
weakly sensitive to Re



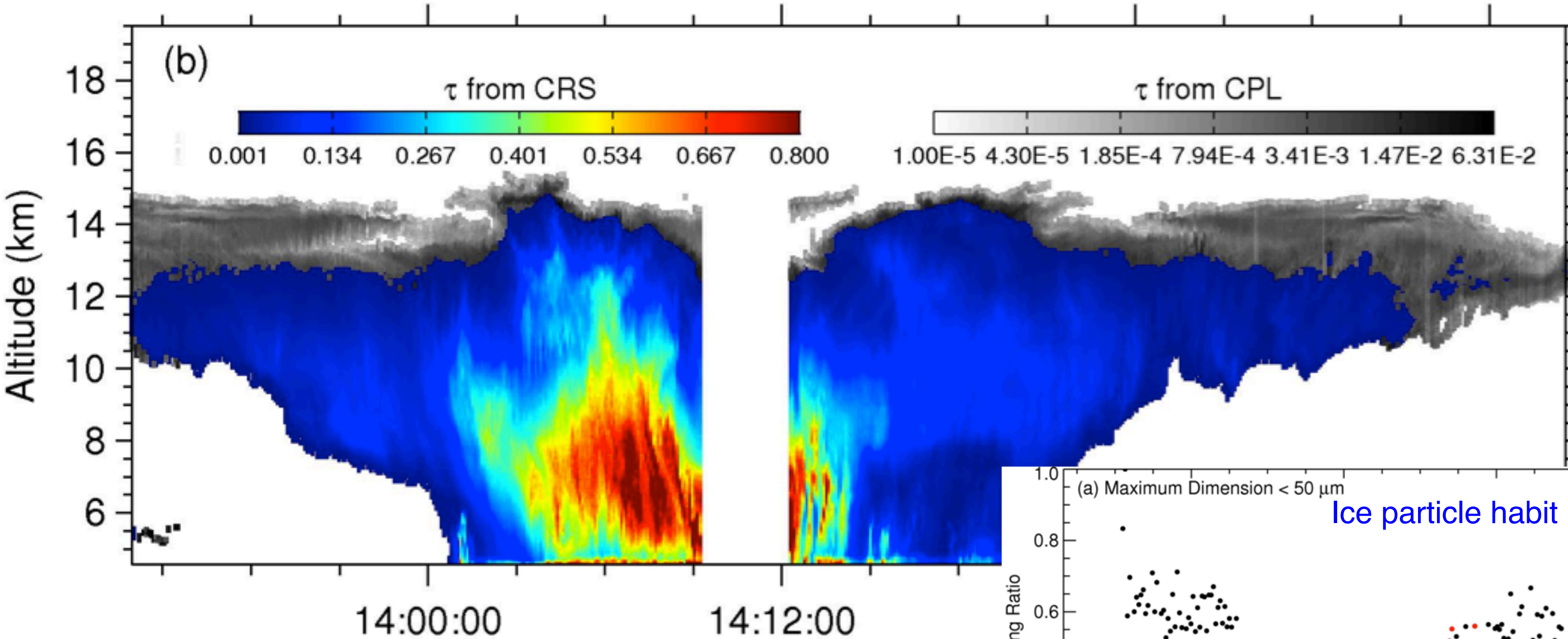
Optical thickness from 6.7 and 11.0 µm vs. VISST Retrievals

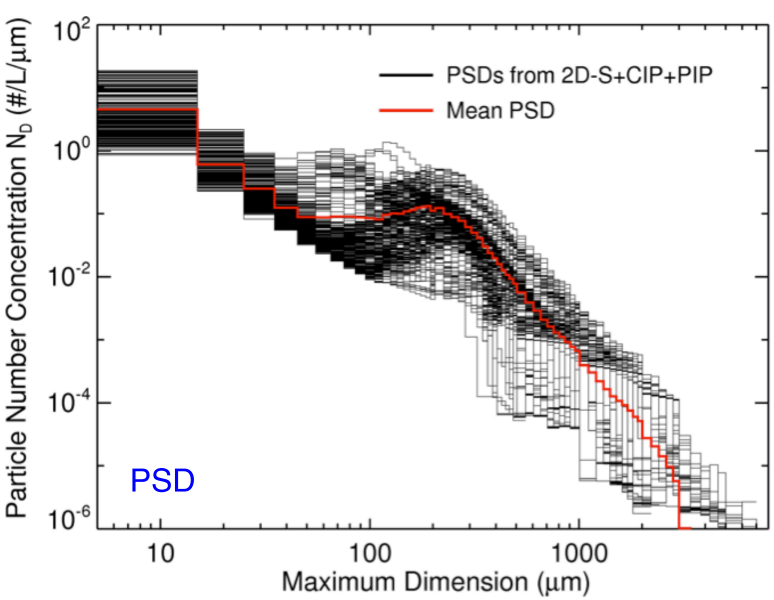
VISST - the Visible Infrared Solar-infrared Split Window Technique (Minnis et al., 1998, 2011)

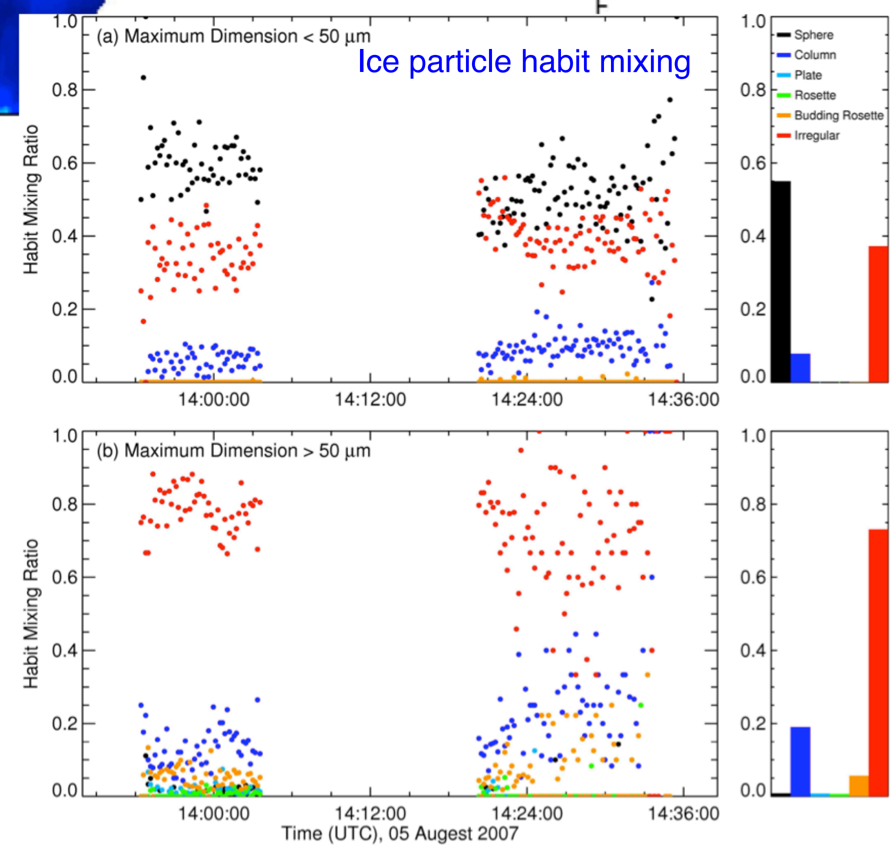


Opaque Ice Cloud Optical Thickness from IR Retrieval - Blackbody Limitation

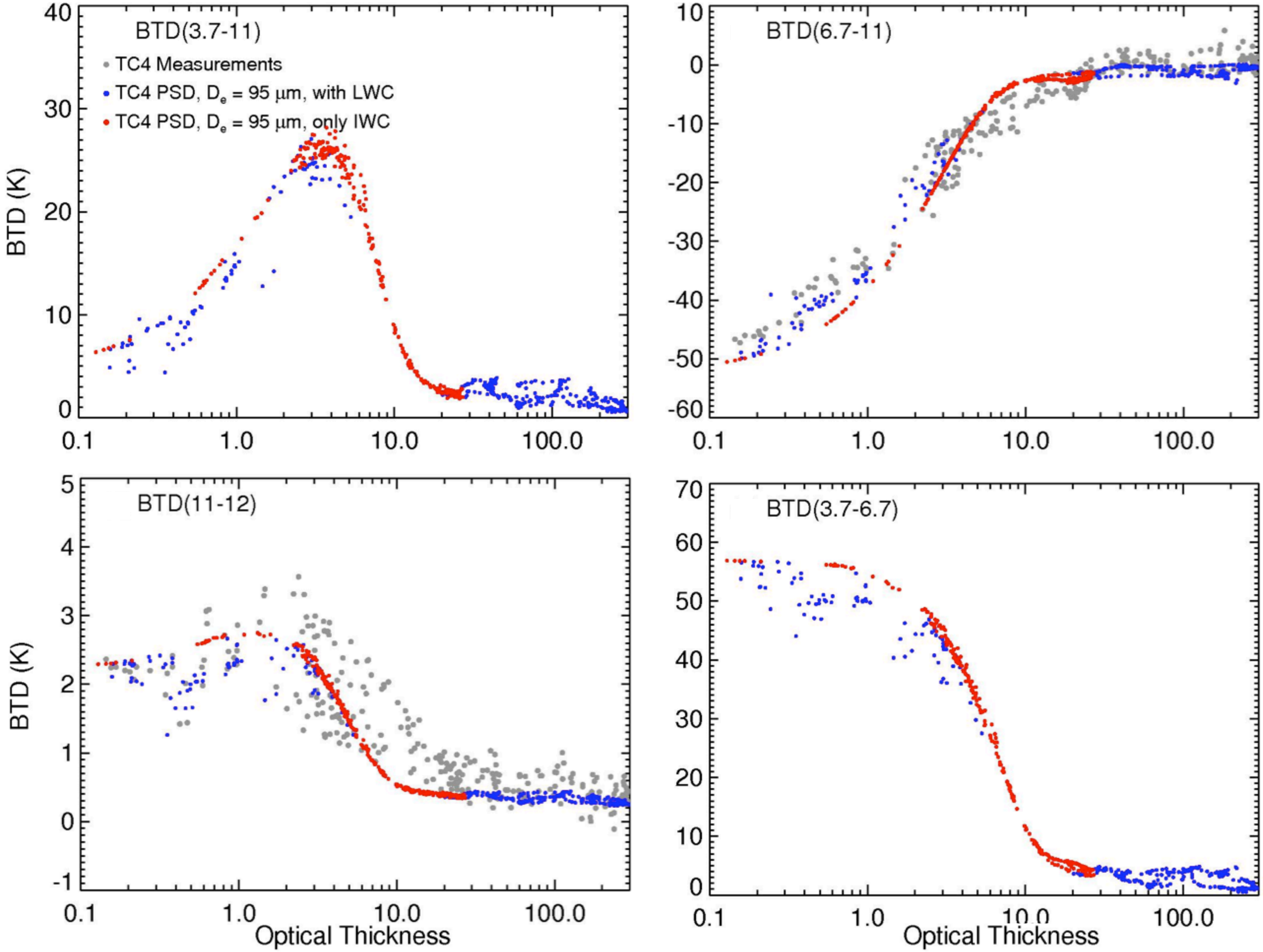
IR Radiances Over DCC: Observations and Simulations (Minnis, Hong, and et al., 2012)





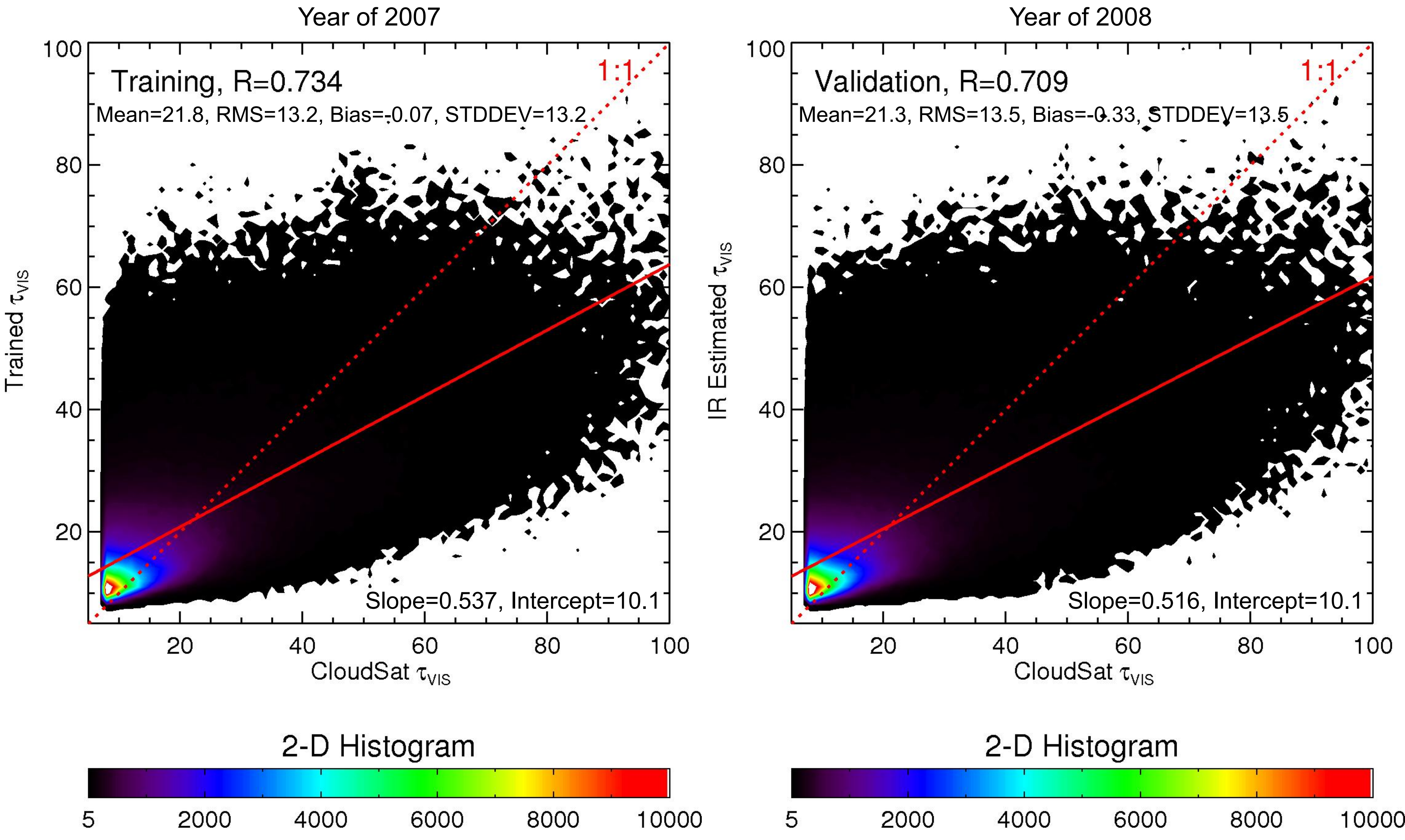


IR Radiances Over DCC: Observations and Simulations (Minnis, Hong, and et al., 2012)

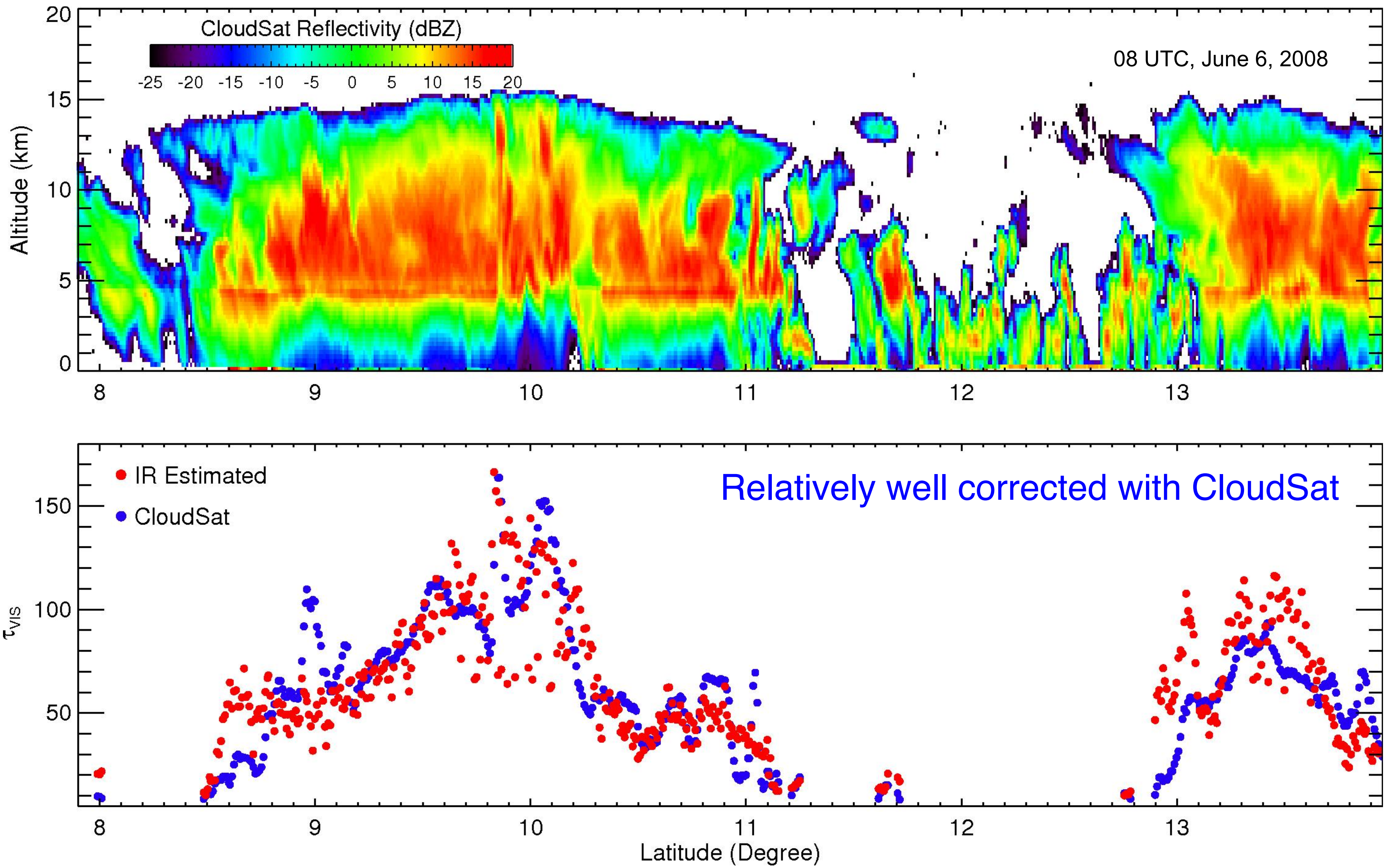


Opaque Ice Cloud Optical Thickness from IR Measurements: Neural Network Training and Validation

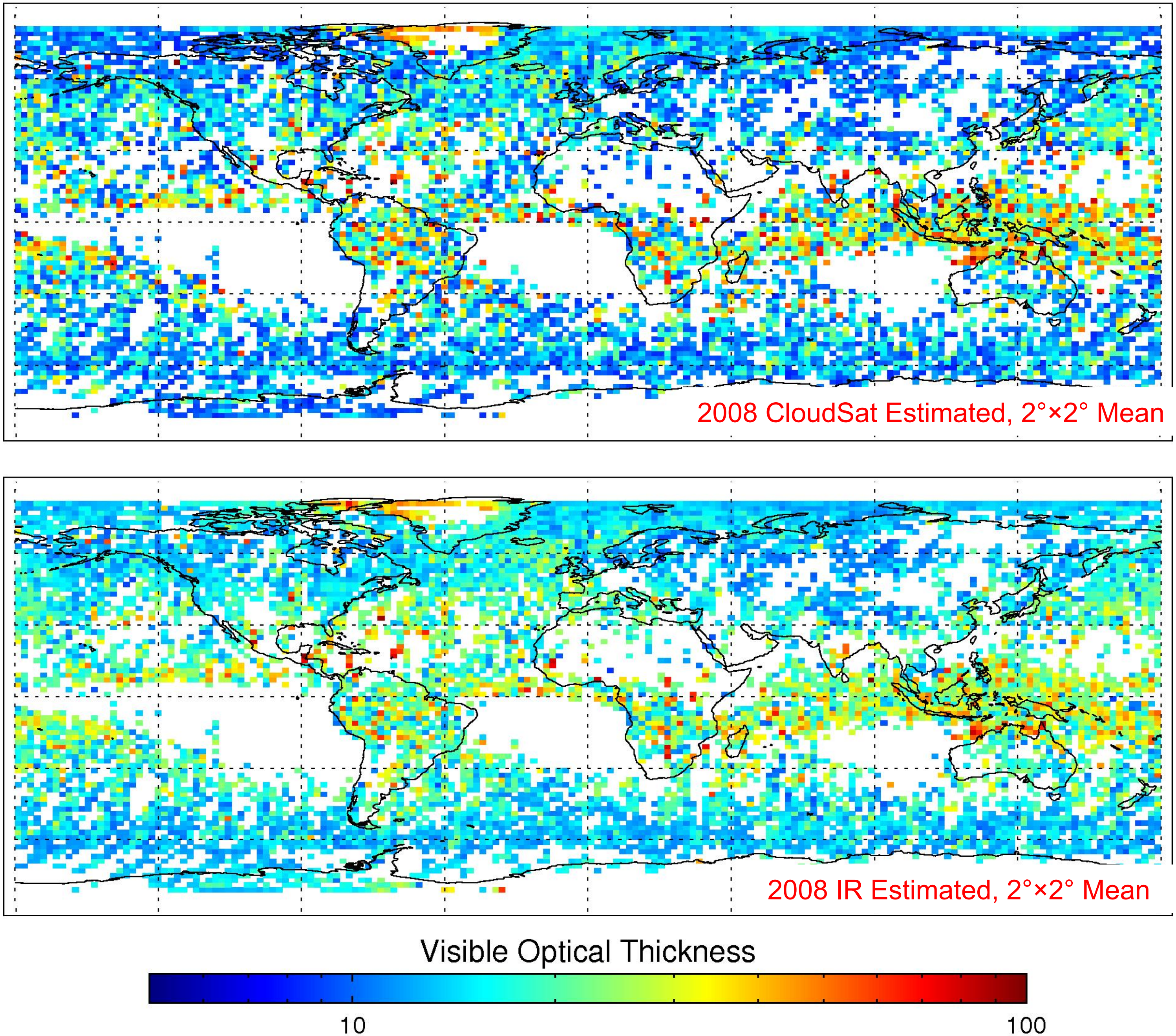
Training data: 2007 LaRC C3M Data at night (globally) *(Kato et al., 2011)*
Validation data: 2008 LaRC C3M Data at night (globally)



Opaque Ice Cloud Optical Thickness from IR Measurements: An Example of Application



Geographical Distribution of Opaque Ice Cloud Optical Thickness at Nighttime



Summary

- Water vapor band at 6.7 µm and IR window band at 11.0 µm are used to estimate non-opaque ice cloud-top temperature. Agree well with CO_2 slicing method, slightly higher.

- After obtaining Tc, Nε and Tau of non-opaque ices are derived from parameterization method and physical retrieval method. Tau is very consistent with the results from visible measurements.

- Opaque ice clouds become IR blackbody emission

  Rigorous radiative transfer modeling using *in situ* measurements indicates that 3.7, 6.7, 11.0, and 12.0-µm still show some sensitivities to opaque ice cloud, at least to Tau ~ 20.

- Go beyond IR blackbody limitation for estimating opaque ice cloud Tau from a neural network method built on the basis of collocated MODIS IR measurements and CloudSat-derived Tau in 2007.
  2008 data used to validate the technique find that IR-estimated Tau agrees with CloudSat-derived Tau for opaque ice clouds with uncertainty of ~63%.